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Two Flavors of El Niño and Its Predictability

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1. Introduction

The systematic errors of CGCMs have a profound influence on the capability of theses climate models to simulate the fluctuations of the tropical climate. Therefore, the characteristics of systematic errors are a fundamental issue in studies of the limit of predictability of the coupled ocean–atmosphere system. Forecast errors depend on a given model's characteristics, in particular, after the influence of the initial conditions fades out with respect to lead time in a forecast (Jin *et al.* 2008; Jin and Kinter 2009). Focusing on the tropical SST predictability, model errors associated with the El Niño and the Southern Oscillation (ENSO) mechanism may have a strong impact.

Different from the definition of conventional El Niño which is as a phenomenon in the equatorial Pacific Ocean characterized by a positive sea surface temperature departure from normal in the Niño -3.4 region (*i.e.*, 5°S–5°N, 170°–120°W) greater than or equal in magnitude to 0.5°C averaged over three consecutive months (National Oceanic and Atmospheric Administration), there have been several studies to define the different flavors of El Niño (or ENSO) (Trenberth and Stepaniak, 2001; Larkin and Harrison 2005; Ashok *et al.* 2007; Guan and Nigam, 2008; Kao and Yu 2009). Even though there are differences among studies, the distinctive interannual SST variation over the central Pacific which becomes more active in recent years and significantly different global impact from conventional El Niño are common features. Recently, Kug *et al.* (2009) shows that the transition mechanisms and dynamical structure of two-types of El Niño are significantly different.

The main objective of this study is to investigate the predictability of different flavors of ENSO in the state-of-the-art CGCMs. Based on previous definitions, CGCM's ability to predict the distinguishable characteristics of two types of El Niño is investigated using two state-of-the-art CGCMs retrospective forecasts dataset. The ensemble forecasts of the tropical Pacific in 2 CGCMs have been compared with each other and with observations.

2. Data and model

Two retrospective forecast data set of NCEP CFS (Saha *et al.* 2006) and FRCGC/SINTEX-F (Luo *et al.* 2005) are used. A set of retrospective ensemble forecast data set of NCEP CFS was created by running a 9-month integration of 15 members for each of the 12 calendar months in the 27 years from 1981 to 2007. A set of ensemble forecast with 9 members of FRCGC/SINTEX-F was created by running a12-month integration for each of the 12 calendar months in the 26 years from 1982 to 2007. Note that forecast data used here is reconstructed with respect to lead time using all data starting from 12 calendar months to focus on the change of predictability with respect to lead month. The initialization processes of two models are independent. With these retrospective forecasts, a 52-year of NCEP CFS and 200-year of SINTEX-F long run were analyzed to investigate the characteristics of model error.

In this study, SST is mainly used as the variable which represents the coupled system. For comparison with observation, the Optimum Interpolation Sea Surface Temperature (OISST) analyses dataset (Reynolds and Smith 1994) created by the Climate Prediction Center (CPC) of the National Centers for Environmental Prediction (NCEP) is used.

3. Two flavors of El Niño and its predictability

The definition of two types of El Niño is as follows. El Niño events show stronger SST anomalies over the eastern Pacific, and it is elongated to the central Pacific, we will refer these El Niño events to Cold tongue

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(CT) El Niño. The SST pattern of CT El Niño is quite similar to that of conventional El Niño (Rasmusson and Carpenter 1982; Harrison and Larkin 1998; Kug et al. 2009). Unlike CT El Niño events, some El Niño events have larger SST anomalies over the central Pacific, while the eastern Pacific SST is small but still positive. Hereafter, we will call these El Niño events as Warm Pool (WP) El Niño events. Both El Niño shows different rainfall patterns which induce different global impact. The CT El Niño is characterized by relatively large SST anomalies in the NIÑO3 region (5ºS–5ºN, 150º–90ºW), while the WP El Niño is associated with SST anomalies mostly confined to the NIÑO4 region (5ºS–5ºN, 160ºE–150ºW). During 1981 to 2006, this is the individual case of three categories. The 82-83 and 1997-98 events are CT El Niño and the 1990-91, 1994-95, 2002-03, and 2004-05 events are WP El Niño. There are three more events, which have features between the CT and WP El Niño events: the 1986–88 and 1991–92 events.

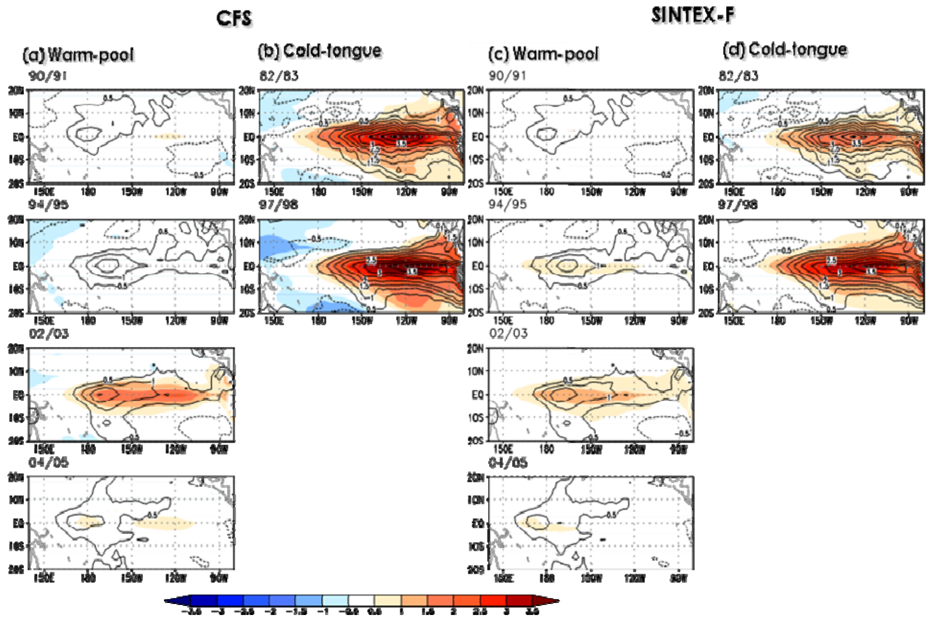

Figure 1. Observed and simulated DJF SST anomalies of WP and CT El Niño cases at the forecast lead month 6. (a) CFS WP El Niño, (b) CFS CT El Niño, (c) SINTEX-F WP El Niño and (d) SINTEX-F CT El Niño. Solid line denotes observation and shading denotes model.

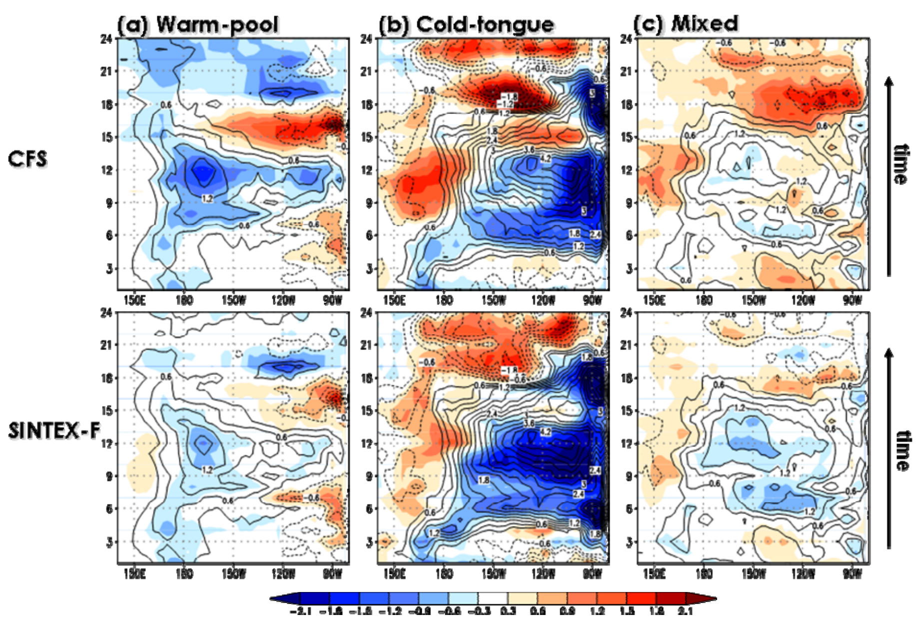

Figure 2. WP, CT and mixed El Niño composite of SST anomalies along the equator at the forecast lead month 7. Solid line denotes observation and shading denotes composite bias of model forecast by subtracting observation from model forecast. (a) CFS and SINTEX-F WP El Niño, (b) CFS and SINTEX-F CT El Niño and (c) CFS and SINTEX-F mixed El Niño.

The predictability of individual case of CT and WP El Niño is considered. In the case of forecast lead month 1 (not shown), both models show quite good accordance with observed pattern. Comparing two models, CFS tend to underestimate the magnitude of anomalies more than SINTEX. Figure 1 shows the individual case of CT and WP El Niño at the forecast lead month 6. In this plot, the contour is for observation and the shading is for model forecast. It looks that models reproduce the CT El Niño better than WP El Niño.

The differences of magnitude of SST anomalies can be one factor because CT El Niño is stronger than WP El Niño in general.

To describe the distinctions in characteristics of CT and WP El Niño events and its predictability, a composite analysis is performed. The ensemble mean of forecast data is reconstructed with respect to lead month and then WP, CT and mixed El Niño events composites are calculated. Figure 2 shows the bias composite along the equator at the forecast lead month 7. The contour denotes observed composite and the shading denotes error composite of model forecast from observation. Observed composites show distinctive centers of action for CT, WP and mixed El Niño, respectively. Interestingly, both models commonly underestimate the SST anomalies over the center of action, where the maximum positive SST anomaly is shown in observation. Negative bias is shown in the warm pool region for WP El Niño and negative bias is shown in the cold tongue region for CT El Niño. As a result, the sign of model error is opposite of that of observed SST anomaly. The errors of mixed case of El Niño are relatively small. Regardless of the independency of dynamics, physics and initialization process of two models, similarity of forecast errors at long forecast lead month in CT and WP El Niño is very intriguing.

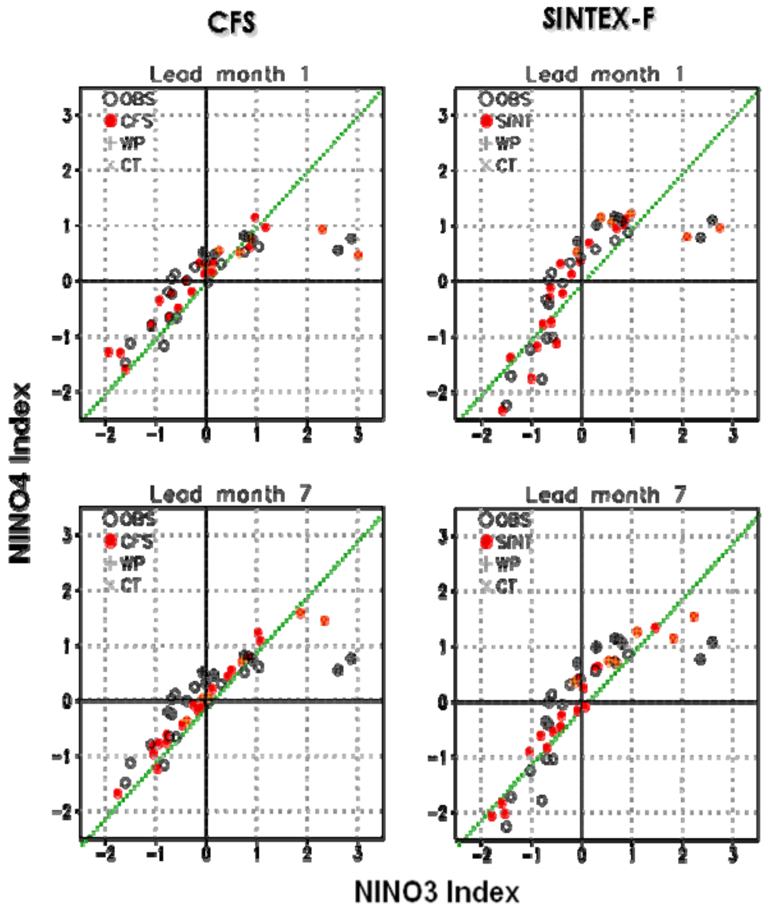

Figure 3. The scatter diagram of normalized NIÑO3 and NIÑO4 index. Upper panels show CFS and SINTEX-F at the forecast lead month 1 and lower panels show CFS and SINTEX-F at the forecast lead month 7. Black circle is for observation, red circle is for model and WP and CT cases denotes as cross and x, respectively.

Focusing on the NIÑO indices, the normalized interannual variability of NIÑO3 and NIÑO4 index with respect to lead month is calculated (not shown). Even though the detailed forecast skill has differences in two models, their tendency looks similar. With respect to increase of lead month, models tend to simulate the regular amplitude of two indices and the difference of two indices gets smaller.

Figure 3 is the scatter diagram of normalized NIÑO3 and NIÑO4 index. Black circle is for observation, red is for model forecast, and WP and CT cases are shown as cross and x, respectively. The X axis is NIÑO3 SST anomalies and the y-axis is NIÑO4 SST anomalies. The dashed green line is the indication of linearity between two indices. In observation, it is shown that CT El Niño events are clear outliers from linear relationship and WP El Niño events also show somewhat nonlinear relationship between NIÑO3 and NIÑO4 SST anomalies. This is reasonable considering the definition of CT and WP El Niño. In the case of forecast lead month 1 (upper panels), both models show good accordance with observed relationship as expected. At forecast lead month 7 (lower panels), red circles shows that the nonlinear relationship between two indices almost gets disappeared. Different from observation, their relationship looks very linear in model forecast.

The correlation coefficient between NIÑO3 and NIÑO4 index is 0.69 in observation. At the forecast lead month 1, the correlation coefficient in SINTEX-F indicates 0.73 and CFS indicates 0.77 and it is well matched with the fact that SINTEX-F shows small forecast error. However, models show increase of relationship with respect to increase of lead month. Models show the increase of relationship to 0.9 and it is associated with drop of forecast skill.

These results indicate that the centers of action of two models in each case of CT and WP El Niño tend to move close to the mixed mode with respect to the increase of lead month. In the previous study, we showed that model's error associated with ENSO dynamics which is different from observation degrades the ENSO forecast skill despite of the advantageous impact of initial condition (Jin and Kinter 2009). Hence, common ENSO forecast errors of two CGCMs at the long lead month can be associated with common errors of ENSO dynamics in CGCMs. To distinguish a given model's problematic features away from the influence of initial conditions, the analysis of ENSO characteristics in long simulations made with the coupled GCMs that are used for operational SST forecasting can be useful. To investigate the relationship between long run behavior and model forecast error, 52-year long run of CFS and 200-year long run of SINTEX-F are used.

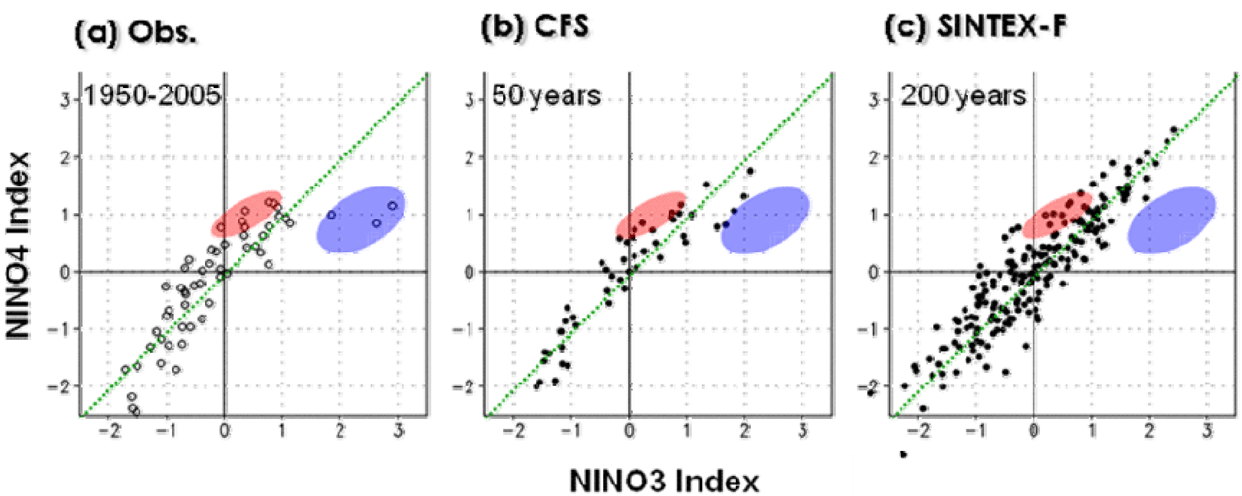

Figure 4. The scatter diagram of normalized NIÑO3 and NIÑO4 index. Right panel shows observation (ERSST and OISST), middle panel shows CFS long run, and left panel shows SINTEX-F long run.

The scatter diagram of normalized NIÑO3 and NIÑO4 index of long run is shown in Figure 4. Blue shading area denotes CT El Niño and red shading area denotes WP El Niño, respectively. In both models, most of El Niño events occurred show linear relationship between NIÑO3 and NIÑO4 index suggesting that most of El Niño events are close to the mixed mode. Overall, the correlation coefficient between NIÑO3 and NIÑO4 index is higher than observation as 0.82 in CFS and 0.86 in SINTEX-F. It suggests that CGCMs have common flaw having monotonic flavor of El Niño and fail to reproduce the complexity in nature. This defect is also associated with the failure of distinguished forecast of different flavors of El Niño, in particular at the long lead month.

4. Concluding remarks

In two state-of-the-art CGCMs, the forecast skill of El Niño is investigated focusing on two flavors of El Niño, which are cold-tongue (CT) and warm-pool (WP). As the lead month of forecast increases, the models fail to distinguish between two flavors of El Niño. Both models have difficulties to reproduce the nonlinear relationship between NIÑO3 and NIÑO4 SST anomalies at the long lead forecast month. This problematic feature is related with the forecast skill of ENSO.

Among several factors to limit the predictability of ENSO in coupled models, model flaw is one of most dominant problems to degrade the forecast skill. From the long run, it is found that models commonly tend to simulate monotonic flavor of El Niño which is close to the mixed mode rather than CT and WP El Niño. This is one of the common errors of two CGCMs associated with drop of ENSO forecast skill at the long lead month of retrospective forecasts. This common flaw in models suggests that the distinctive transition mechanism associated with the spatial structure of SST and the relative importance of advective and thermocline feedbacks between the two types of El Niño in nature (Kug et al., 2009) is not reproduced in models. Further analysis will be needed to verify this point of view.

The predictability of El Niño on seasonal time scales is important because of the associated global-scale climate anomalies of precipitation and near-surface air temperature (Ropelewski and Halpert 1987; Trenberth et al., 1998; Mason and Goddard 2001). The different pattern of the anomalous convection can lead to difference of the atmospheric circulation, and one may expect distinctive teleconnection of two El Niño events because the tropical precipitation is a key source of the extra-tropical teleconnections. Further research will focus on the tropical precipitation and teleconnection anomalies associated with two flavors of El Niño and its predictability.

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